UNITED
NATIONS

E

Economic and Social Council

Distr.
LIMITED

E/CONF.83/L.33
21 January 1991

ENGLISH ONLY

TWELFTH UNITED NATIONS REGIONAL
CARTOGRAPHIC CONFERENCE FOR
ASIA AND THE PACIFIC
Bangkok, 20-28 February 1991
Item 5 (d) of the provisional agenda*

CARTOGRAPHIC DATA ACQUISITION AND SUPPORTING ACTIVITIES: HYDROGRAPHIC SURVEYING AND NAUTICAL CHARTING

Ocean mapping activities of the Intergovernmental Oceanographic Commission**

Paper submitted by the Intergovernmental Oceanographic Commission***

---

* E/CONF.83/1.

** Copies of the report of the IOC *ad hoc* Group of Experts on Ocean Mapping in the WESTPAC region, Tianjin, China, June 1990 (IOC/GE-IBCWP-I/3) which gives more information on IOC's plans for an International Bathymetric Chart of the Western Pacific will be made available. However, the project is in an early stage of development and awaits approval by the IOC Assembly at its sixteenth session in March 1991.

*** Prepared by Desmond P. D. Scott, Chairman of the IOC Consultative Group on Ocean Mapping and Viktor Sedov, of the IOC secretariat.

READEX
FICHE

TABLE OF CONTENTS

		Page
1.	BACKGROUND	3
2.	THE CONSULTATIVE GROUP ON OCEAN MAPPING (CGOM)	5
3.	GENERAL BATHYMETRIC CHART OF THE OCEANS (GEBCO)	5
4.	INTERNATIONAL GEOLOGICAL/GEOPHYSICAL ATLASES OF THE ATLANTIC AND PACIFIC OCEANS (GAPA)	6
5.	INTERNATIONAL BATHYMETRIC CHART OF THE MEDITERRANEAN AND ITS GEOLOGICAL/GEOPHYSICAL SERIES (IBCM)	6
6.	INTERNATIONAL BATHYMETRIC CHART OF THE CARIBBEAN SEA AND GULF OF MEXICO (IBCCA)	8
7.	INTERNATIONAL BATHYMETRIC CHART OF THE WESTERN INDIAN OCEAN (IBCWIO)	8
8.	INTERNATIONAL BATHYMETRIC CHART OF THE CENTRAL EASTERN ATLANTIC (IBCEA)	8
9.	INTERNATIONAL BATHYMETRIC CHART OF THE WESTERN PACIFIC (IBCWP)	9
10.	OTHER POSSIBLE REGIONAL OCEAN MAPPING PROJECTS	9
11.	CONCLUSION	10
ANNEX I	STRUCTURAL DIAGRAM FOR THE "GEBCO DIGITAL ATLAS"	11
ANNEX II	ASSEMBLY DIAGRAMS FOR THE EXISTING AND PLANNED IOC OCEAN MAPPING PROJECTS	12

/...

1. BACKGROUND

The bottom of the World's Oceans covers more than two thirds of the surface of the globe, and its relief is more complicated than that of the land because it is less subject to changes wrought by erosion. Besides this, the oceanic crust is much younger than continental blocks and is not so thick. For these reasons the roughness of the ocean bottom is more strongly expressed.

The latest technological achievements in cartography on land, particularly the use of remote sensing, cannot be applied to the development of marine cartography because of the impenetrability of ocean water masses by light beams. This is why at the present time the topography of the seafloor is not as well known as the topography of the far side of the moon.

But the need for exploitation of ocean resources increases each year, and requires careful regulation based upon a detailed knowledge of the marine environment.

One of the first and most important steps in the exploration of the oceans is the preparation of bathymetric charts showing the topography of the ocean bottom in as much detail as possible. For this reason, ocean mapping has made considerable progress in recent years and has become one of IOC's major activities.

But for compilation of bathymetric charts a knowledge of the measured depth alone is not enough. Knowledge of the geomorphology, geology and sedimentology of the seafloor is also essential; for this reason the involvement of the IOC scientific community is therefore extremely important. On the other hand, the production of bathymetric charts can also be a stimulus to the research of many marine scientists because the topography of the seafloor strongly influences physical, chemical and biological processes, especially in the near bottom layers.

The great majority of existing bathymetric data still in use today is of low quality by modern standards. Uncertainties in the determination of ship's position limit the accuracy of the isobaths.

The IOC, working in close collaboration with the International Hydrographic Organization, co-ordinates international efforts to archive all existing available data, to undertake additional investigations in some regions, and to compile and print bathymetric charts to meet the needs of all types of ocean users.

All bathymetric charts compiled under the aegis of the IOC are prepared to a common standard in regard to cartographic specifications and legends. They are all designed to meet the following requirements:

(i) Simple, easy to read, clear;
(ii) Provision of correct and comprehensive information on the bottom topography;
(iii) Provision of the most detailed and accurate value available for the depth at any point on the sheet.

In recent years, many national and international organizations have taken on the task of compiling charts for various ocean regions. In certain cases this has been undertaken principally to facilitate the exploitation of particular ocean resources. The IOC's aim is to ensure a planned approach to the long-term mapping of the world seabed, not only to meet current needs but in the perspective of the long-term development of ocean sciences and services.

In general for any given ocean region, a bathymetric chart is first compiled which serves as a base chart; following this, geological and geophysical maps (overprinted on the base chart) are prepared. The same base chart can also be used for the compilation of charts showing the distribution and circulation of water masses and of living and non-living resources.

The IOC has been active in Ocean Mapping since the United Nations General Assembly endorsed, by Resolution 2560 (XXIV) in December 1969, the Long-term and Expanded Programme of Oceanic Exploration and Research (LEPOR). In 1970 the compilation of a Geological/Geophysical Atlas of the Indian Ocean was started (published 1975) in order to compile in map form the findings of the International Indian Ocean Expedition (IIOE). In 1972 the IOC and the International Hydrographic Organization (IHO) agreed to co-sponsor the production of a new (fifth) edition of the General Bathymetric Chart of the Oceans (GEBCO). The GEBCO (5th Edition), published in 1982 by the Canadian Hydrographic Service (on behalf of IOC and IHO), consists of 19 sheets depicting the bathymetry and morphology of the world's oceans; this series takes advantage for the first time of the development of new concepts of global tectonics and modern navigational systems.

In 1973, following IOC Resolution VIII-11, a group of experts was set up to prepare a large-scale bathymetric base chart of the Mediterranean and Black Seas. With the co-operation of the IHO, national hydrographic services and individual scientists, the First Edition of the International Bathymetric Chart of the Mediterranean (IBCM) was printed and published by the Head Department of Navigation and Oceanography, Leningrad, on behalf of the IOC, in 1982. IBCM Geological-Geophysical series are in course of preparation.

The IOC has now set up an effective structure of subsidiary groups and editorial boards for its Ocean Mapping programme. The activities of the various groups are described in the remaining sections of this paper.

2. THE CONSULTATIVE GROUP ON OCEAN MAPPING (CGOM)

At its Seventeenth Session in January-February 1984, the IOC Executive Council established the Consultative Group on Ocean Mapping (CGOM), as it had become apparent that there was a need to have within the structure of the IOC an appropriate advisory body formed of highly-qualified scientists in the field of ocean mapping and related activities, to act as an overall technical mechanism linking together the diverse ocean mapping projects with which the Commission is involved.

The CGOM is composed of the Chairmen of all the supervisory groups and editorial boards of the Ocean Mapping projects sponsored or co-sponsored by the Commission. It meets to discuss current developments and reports biennially to the IOC Assembly.

3. GENERAL BATHYMETRIC CHART OF THE OCEANS (GEBCO)

The General Bathymetric Chart of the Oceans was initiated at the beginning of the century by Prince Albert I of Monaco. The first edition was published in 1903. The success of the chart inspired scientists to continue preparations for further editions. By 1972, four editions had been either completely or partially published, but then, following a strong recommendation from the Scientific Committee on Oceanic Research (SCOR) on content and general requirements, the IOC and the IHO agreed to co-sponsor an entirely new (fifth) edition, to be compiled by marine scientists, incorporating the best available bathymetric data and employing the latest geological and geophysical knowledge of the structure of the seafloor.

A Joint IOC-IHO Guiding Committee for the GEBCO was established consisting of ten members, five nominated by IOC and five by IHO. The IOC experts are nominated after consultation with the Scientific Committee on Oceanic Research (SCOR), the International Association for the Physical Sciences of the Ocean (IAPSO) and the Commission for Marine Geology (CMG). The IHO experts are selected from Volunteering Hydrographic Offices (VHOs).

With such close collaboration between scientists and hydrographers, the Fifth Edition of GEBCO was completed by 1982; it consists of 16 sheets on Mercator projection at a scale of 1:10 million (at the equator), 2 sheets on Polar Stereographic projection at a scale of 1:6 million (at 75° latitude), and, published in 1984, the World's Oceans in one sheet, on Mercator projection at a scale of 1:35 million (at the equator) with the polar regions at a scale of 1:25 million (at 75° latitude).

A GEBCO Sub-Committee on Geographical Names and Nomenclature of Ocean Bottom Features was set up at the same time as the Guiding Committee to oversea the standardization of nomenclature used for ocean bottom features, together with their geographical names. In late-1988 a "Gazetteer of Geographical Names of Undersea Features shown (or which might be added) on the

GEBCO and on the IHO small-scale International Chart Series" was published in English and French. This incorporates the English/French version of a publication "Standardization of Undersea Feature Names"; English/Russian and English/Spanish versions have been published separately. English/Chinese, English/German, English/Japanese and English/Portuguese versions are in preparation.

The Guiding Committee has concluded that the future of the GEBCO lies with the development of a continuously updated digital bathymetric contour database, together with appropriate sub-files. Products from the database are marketed using current technology, and a new edition of the traditional GEBCO printed map series will be published from time to time as appropriate, and when funds permit.

This database, which will be easily accessible and user friendly, has now been named the "GEBCO Digital Atlas". Initially it will consist of a collection of digitized bathymetric contour maps of the world's oceans, with sub-files for track control, and a gazetteer of undersea feature names. Later, it is planned to add a Digital Terrain Model and/or a gridded data set, and to create a CD-ROM for use on Personal Computers (PCs).

Magnetic tapes of digitized bathymetric contours of certain regions are already available, and the "GEBCO Digital Atlas" is expected to be fully operational by mid-1991 (see Annex I). A new 6th Edition of the GEBCO traditional printed paper chart is now scheduled for publication in 1995.

4. INTERNATIONAL GEOLOGICAL/GEOPHYSICAL ATLASES OF THE ATLANTIC AND PACIFIC OCEANS (GAPA)

The Geological/Geophysical Atlas of the Indian Ocean was published in 1975, under the overall supervision of the IOC, to bring together all data collected during the International Indian Ocean Expedition (1959-1965).

Further atlases in this series consist of an Atlantic ocean atlas (published 1990) and a Pacific Ocean atlas (in preparation and scheduled for publication by the end of 1993). The numerous maps therein of various parameters are being compiled by eminent marine geologists and geophysicists working in leading scientific institutions throughout the world.

5. INTERNATIONAL BATHYMETRIC CHART OF THE MEDITERRANEAN AND ITS GEOLOGICAL/GEOPHYSICAL SERIES (IBCM)

The IBCM was the first IOC regional mapping project. It was initiated by scientists participating in the joint IOC/ICSEM/FAO Co-operative Investigations in the Mediterranean (CIM), in the early 1970s, and it can be said that at the present time the Mediterranean has become one of the best explored regional seas in the world, from the point of view of cartography of the sea bottom.

Several bathymetric charts of limited areas already existed at that time, some on scales as large as 1:200,000. However, development of high precision echo-sounding and positioning techniques made it possible to collect a large amount of new data in a relatively short space of time. This became an essential premise for the preparation of high quality bathymetric charts of the Mediterranean on a scale of 1:1 million (at 38° North). The chart, consisting of ten sheets on Mercator projection, was printed and published by the Head Department of Navigation and Oceanography, Leningrad, on behalf of IOC, in 1982.

Specifications prepared for compilation of the IBCM have been revised from time-to-time and in 1986 they were adopted by the Consultative Group on Ocean Mapping as "Specifications for International Bathymetric Charts produced under IOC Regional Mapping Projects".

The IBCM contours have been digitized and are now available on magnetic tape to the scientific community at a "symbolic" royalty and reproduction costs.

After the publication of the IBCM, the 1:250,000 plotting sheets were, at the request of the IOC, transferred to the World Data Centre for Bathymetry (IHO). Subsequently, they were distributed to a number of IHO's Volunteering Hydrographic Offices (VHOs) for updating and continued maintenance, with a view to publication of a 2nd Edition of the bathymetric chart later.

Results of the first surveys in the Mediterranean using swath sounding systems, i.e. SEABEAM, SeaMARC, Hollming ECHOS, etc., have recently been received by the WDC Bathymetry, e.g. a survey south of Cyprus carried out by the Soviet R/V "Akademik Nikolai Strakhov". It is expected that in due course a large area of the Mediterranean will be covered by such surveys and that the data will be used by the VHOs for updating the bathymetric database.

Following publication of the IBCM, it was decided to publish five separate geological/geophysical map series (of ten sheets each on the same scale), using the IBCM bathymetry as a base, as follows:

(i) Bouguer Gravity anomalies;
(ii) Seismicity;
(iii) Plio-Quaternary/Messinian Structure;
(iv) Unconsolidated Sea-Bed Sedimentation;
(v) Magnetic anomalies.

The first series (Gravity) has recently been published. The second series (Seismicity) is in press and is scheduled for publication by mid-1991. The other three series are expected to appear thereafter at the rate of one further series a year.

6. INTERNATIONAL BATHYMETRIC CHART OF THE CARIBBEAN SEA AND GULF OF MEXICO (IBCCA)

Preparation of the bathymetric chart covering the Caribbean Sea, Gulf of Mexico and adjacent regions was initiated in 1986. The approved Assembly Diagram provides for 17 sheets on a scale of 1:1 million (at 15° N.). Compilation of a number of sheets has already started and it is expected that the northern ten sheets will be completed by 1992. A colour proof copy of the first of those sheets was printed in 1991.

The IBCCA region has been divided into regions of responsibility for each of the participating countries. The leading role, and responsibility for the final scribing, editing and printing of the chart series has been assumed by the Instituto Nacional de Estadii'stica, Geografi'a e Informa'tica, México.

7. INTERNATIONAL BATHYMETRIC CHART OF THE WESTERN INDIAN OCEAN (IBCWIO)

An Editorial Board for this region has been established with members from countries of the region and other interested countries. Its First Session was held in April 1989 in Antananarivo, Madagascar. At this Session decisions were reached on the overall limits of the region to be charted, the Assembly Diagram showing sheet limits, availability of data, and responsibilities of participating countries.

During the Second Session (July 1990, Mauritius), the first results of the collection and plotting of data were discussed. Plotting sheets of two large areas of the IBCWIO region were displayed for consideration.

The leading role, including provision of the Chief Editor, in editing, printing and publication of this series has been assumed by the Bündesamt für Seeschiffahrt und Hydrographie (BSH), Hamburg, Federal Republic of Germany.

8. INTERNATIONAL BATHYMETRIC CHART OF THE CENTRAL EASTERN ATLANTIC (IBCEA)

An Editorial Board for the IBCEA was established by the IOC Assembly at its Fourteenth Session in March/April 1987.

The Editorial Board during its First Session (February 1990, Nigeria) adopted an Assembly Diagram consisting of 12 sheets to be published by the Hydrographic Services of France and Portugal on behalf of IOC. It was also decided that a digital version of each sheet would be published at the same time as the printed version.

The project will consist of four successive stages:

a) Data Collection - this stage is now operational;
b) Data Quality Control;
c) Geomorphological Interpretation;
d) Printing and Publication of the Chart.

9. INTERNATIONAL BATHYMETRIC CHART OF THE WESTERN PACIFIC (IBCWP)

A meeting of an IOC ad hoc Group of Experts on Ocean Mapping in the WESTPAC Region was held in June 1990 (Tianjin, People's Republic of China).

The Group adopted a recommendation to the IOC Assembly, proposing the creation of this project and the establishment of an Editorial Board for this purpose.

The Group drafted "Specifications for the IBCWP" to be adopted by the Editorial Board".

In view of the large area covered by the WESTPAC Region, the western (marginal) part was divided into six subregions (see Annex II). The compilation, printing and publishing of sheets from these subregions will need to be implemented in different ways, and further negotiations will be needed before the overall mechanisms of implementation can be finalized.

10. OTHER POSSIBLE REGIONAL OCEAN MAPPING PROJECTS

Plans for the preparation of an International Bathymetric Chart of the Red Sea and Gulf of Aden have been drawn up, with the Institute of Oceanographic Sciences Deacon Laboratory, United Kingdom, acting as the lead agency. The project is in abeyance at the present time awaiting identification of the necessary funding source.

The project consists of the base bathymetric series in eleven sheets at a scale of 1:500,000 (at 20°N.) and three separate geological/geophysical map series (of 11 sheets each on the same scale), as follows:

(i) Gravity anomalies;
(ii) Magnetic anomalies (showing seismicity and isochrons on the observe);
(iii) Isopachs (Sediment Thickness).

At meetings of relevant IOC Regional Committees, proposals have been put forward for International Bathymetric Charts of:

(i) The Central Indian Ocean;
(ii) The Antarctic (Southern Oceans).

No firm plans yet exist for these areas.

11. CONCLUSION

As each large-scale regional bathymetric project is completed, it is intended to digitize the contours and other ancillary material. These will then be incorporated into the GEBCO Digital Atlas to replace contours digitized from the smaller scale GEBCO sheets.

The "GEBCO Digital Atlas", together with the recent establishment of an IHO International Data Centre for Digital Bathymetry, will also facilitate the preparation of Digital Terrain Models (DTMs) of the seafloor.

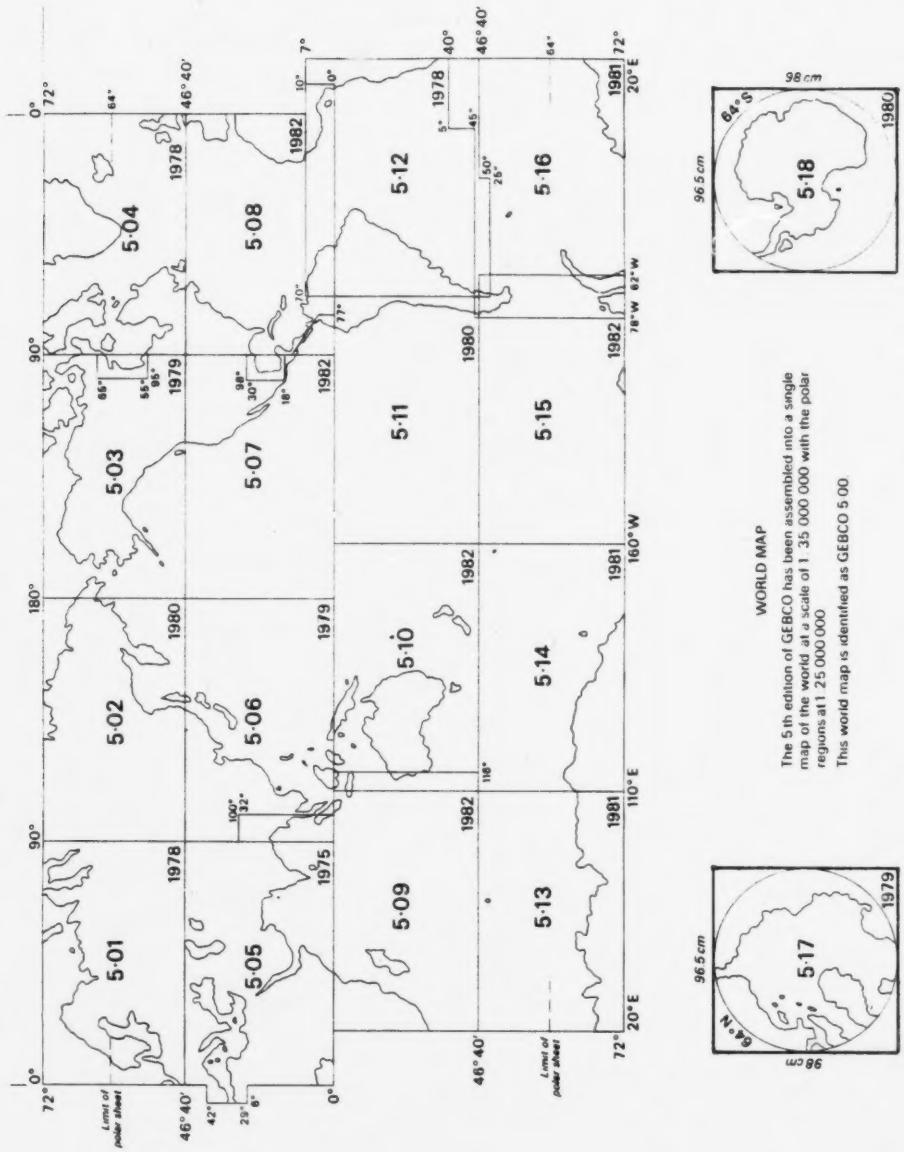
Overall, these activities constitute a significant contribution to the exploration and exploitation of the world's oceans.

ANNEX I

GEBCO STRUCTURAL DIAGRAM

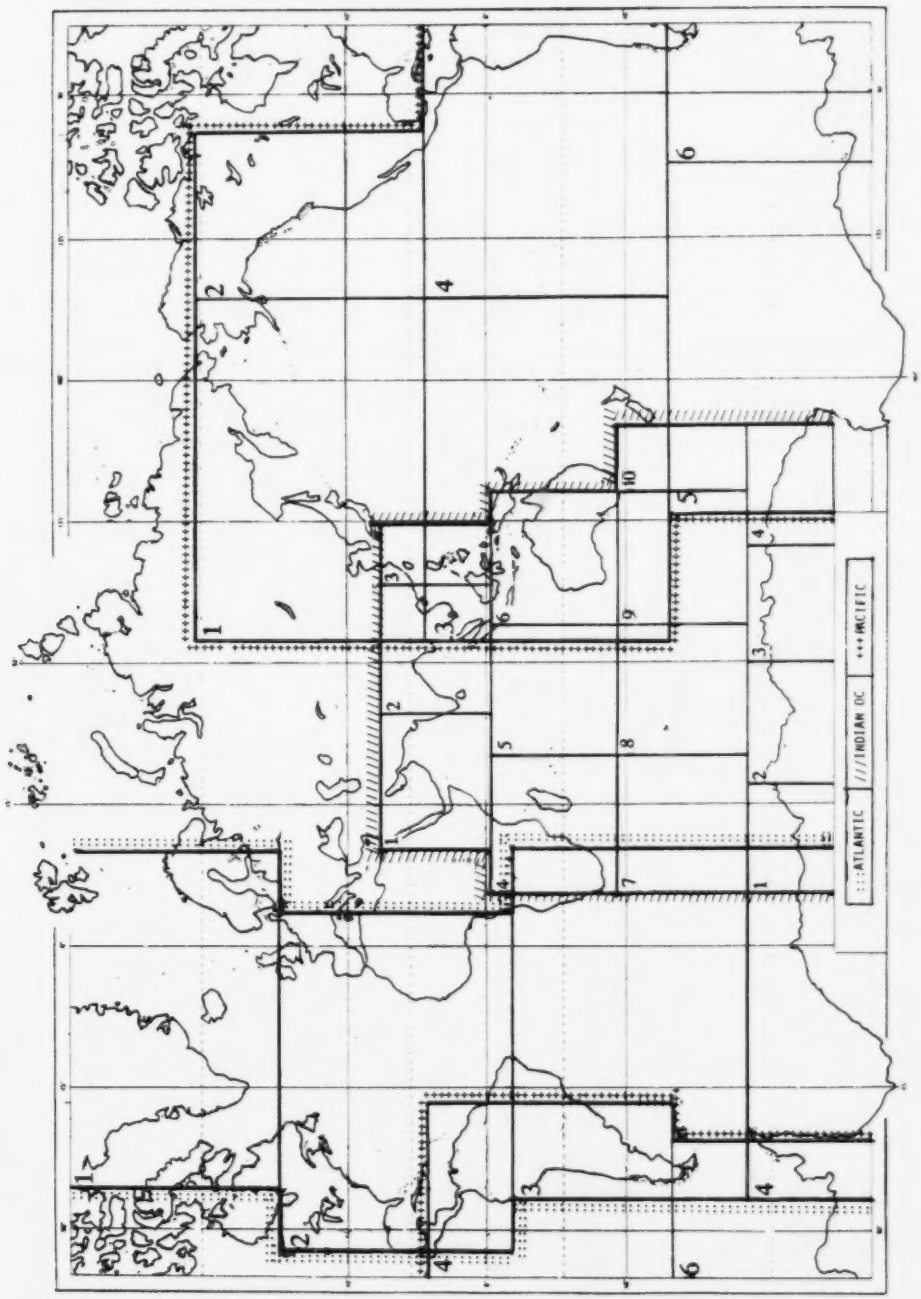
ANNEX II

GENERAL BATHYMETRIC CHART OF THE OCEANS



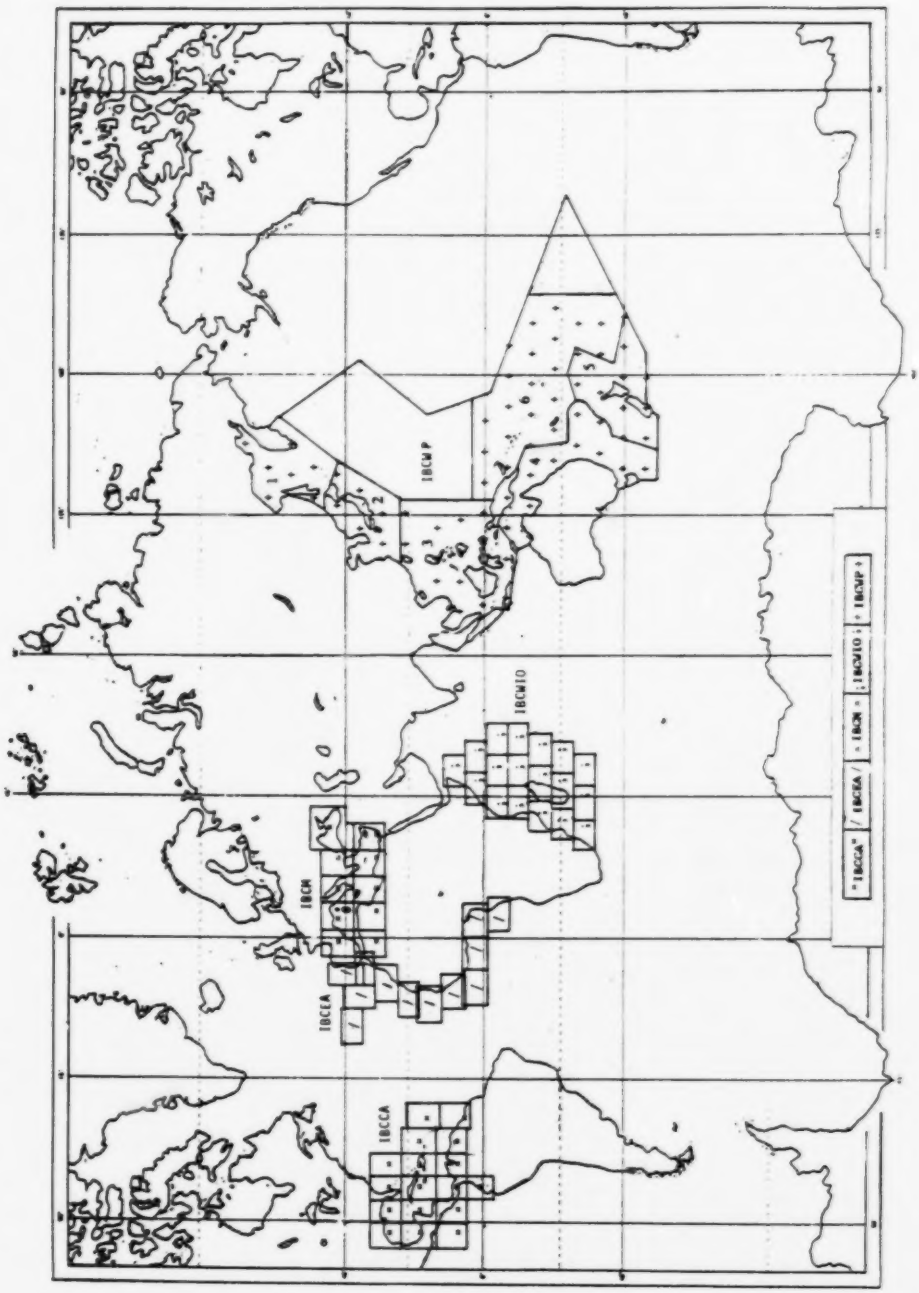
ANNEX II

THE GEOLOGICAL/GEOPHYSICAL ATLASES



ANNEX II

THE REGIONAL IOC OCEAN MAPPING PROJECTS



UNITED
NATIONS

E

Economic and Social Council

Distr.
LIMITED

E/CONF.83/L.34
21 January 1991

ENGLISH ONLY

TWELFTH UNITED NATIONS REGIONAL
CARTOGRAPHIC CONFERENCE FOR
ASIA AND THE PACIFIC
Bangkok, 20-28 February 1991
Item 7 (a) of the provisional agenda*

CARTOGRAPHIC DATA RETRIEVAL, ANALYSIS, DEPICTION, PRESENTATION AND PRODUCT GENERATION: MAP AND CHART REPRODUCTION, PUBLISHING AND PRINTING

Image processing techniques for digital orthophoto production

Paper submitted by the United States of America**

* E/CONF.83/1.

** Prepared by Joy Hood Lyman Ladner and Richard Champion, United States Geological Survey.

Orthophotographs have long been recognized for their value as supplements or alternatives to standard maps. The U.S. Geological Survey (USGS) produces orthophotographs in quadrangle format from a variety of orthophoto instruments, all of which differentially transform a central perspective photograph to an orthogonal projection. With such instruments, scale correction is achieved by adjusting the optical magnification, and direction correction is achieved by image rotation with Dove prisms.

While these techniques produce orthophotographs of high quality, their applications are limited by their photographic form. Recent trends toward digital cartography have resulted the Geological Survey developing the capability to produce digital orthophotos of high spatial resolution from scanned aerial photographs and DEM data.

Digitizing an aerial photograph produces a digital file that represents the gray scale values of a scanned image. Rectification techniques using digital elevation modelling data (DEM's) are applied to the digital image to remove tilt and relief displacement, producing a digital orthophoto.A valuable aspect of a digital orthophoto is that image processing techniques, such as digital mosaicking, image enhancement and data merging, can be applied to improve the usefulness of the data. The capability to mosaic digital orthophotos provides the means to join not only images within a quadrangle but also to join adjacent quadrangles.

Attention is being directed toward improving the efficiency of the techniques and designing a production system. Although much work remains, the digital orthophoto offers great potential to computer-aided cartography.

IMAGE PROCESSING TECHNIQUES FOR DIGITAL ORTHOPHOTOQUAD PRODUCTION

INTRODUCTION

Orthophotographs have long been recognized for their value as supplements or alternatives to standard maps. The U.S. Geological Survey (USGS) produces orthophotographs in quadrangle format from a variety of orthophoto instruments, all of which differentially transform a central perspective photograph to an orthogonal projection. With such instruments, scale correction is achieved by adjusting the optical magnification, and direction correction is achieved by image rotation with Dove prisms.

While these techniques produce orthophotographs of high quality, their applications are limited by their photographic form. Recent trends toward digital cartography have resulted in efforts to develop a digital orthophotoquad production system.

Digitizing an aerial photograph produces a digital file that represents the gray scale values of a scanned image. Rectification techniques applied to the digital image remove tilt and relief displacement, producing a digital orthophoto. A valuable aspect of a digital orthophoto is that image processing techniques, such as digital mosaicking, image enhancement, and data merging, can be applied. A number of experimental digital orthophotos for a variety of applications were produced from photographs of various scales. Final digital orthophoto products include:

Fontana, CA	1:12,000	(mosaic)
Orchards, OR	1:4,800	
Orchards, OR	1:6,000	
Portland, OR	1:12,000	(mosaic)
McCall, ID	1:24,000	(mosaic)
Dane County, WI	1:12,000	(thirty-six quarter quadrangles)

The Fontana, Orchards, and Portland orthophotos were produced as part of an experimental multipurpose cadastre project. Final products included political boundaries, contours lines, place names, and land use indicators either photographically

[1]Work performed under U.S. Geological Survey contract 14-08-0001-22521.

Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Publication authorized by Director, U.S. Geological Survey.

embedded in the images or displayed as overlays. The McCall orthophoto was made from 1:80,000-scale National High Altitude Photography (NHAP) color infrared photography, and the Dane County products were produced from 1:40,000-scale color infrared photography.

PREVIOUS RESEARCH

The idea of a digital orthophoto is not new. Some of the mathematical models for restitution of scanner and scanned images were described by Konecny in 1976. Horton (1978) described a method for generating digital orthophotos through a hardware approach that made use of an image dissector tube to scan imagery nonorthogonally. Keating and Boston (1979) explained a software system to create an orthophoto from digital elevation models (DEM) and imagery scanned on a microdensitometer (an instrument that converts image density at any location to digital form). By 1979, Konecny was able to summarize experiences with digital image rectification software and display photographs of his results. His strategy acknowledged the significance of DEM resolution to the rectification problem and suggested one transformation for DEM cells and a simpler bilinear transformation for picture elements (pixels) within a cell. The present work builds upon that strategy.

DIGITAL RECTIFICATION

The rectification software was developed along the lines proposed by Keating and Boston (1979) and Olsen (1984). The two main sources of input data are a digitized aerial photograph and a DEM. The raster file results from scanning the photograph to be rectified on an Optronics C-4500 drum film scanner. The data of a standard 7.5-minute DEM have the following characteristics: (a) they consist of a regular array of elevations referenced in the Universal Transverse Mercator (UTM) coordinate system, (b) they are ordered from south to north in profiles that are ordered from west to east, and (c) they are stored as profiles in which the spacing of the elevations along and between each profile is 30 m (fig. 1).

In addition to the two main sources of information, several other data files are required. These files consist of ground coordinates of passpoints, photo coordinates of passpoints, camera calibration parameters, and photograph fiducial coordinates in the raster image system.

Initial input to the rectification process consisted of camera calibration parameters, ground coordinates, and photo coordinates of at least three passpoints of the photographs rectified. The exterior orientation of the photographs was solved using the familiar space resection (collinearity) equations (Wolf, 1974) (eq. 1). The six unknown

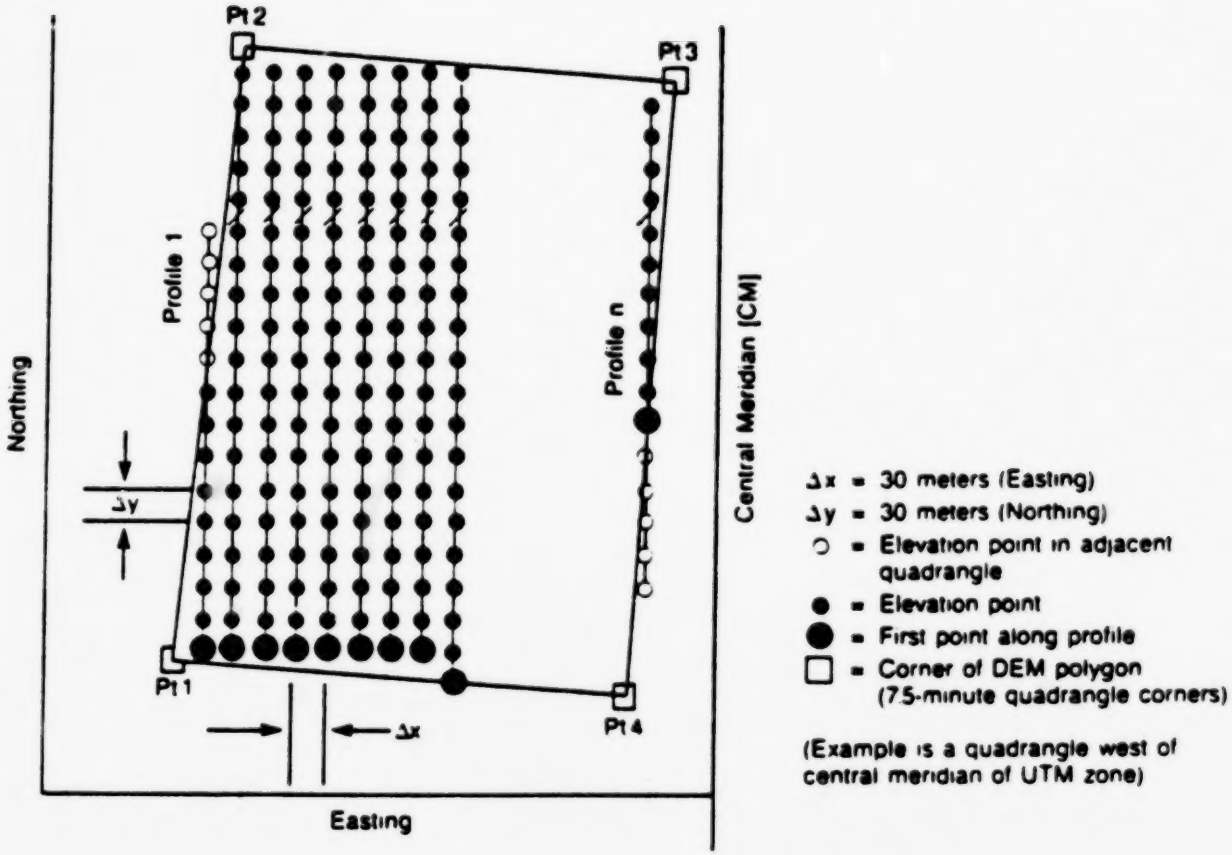


Figure 1. - - Structure of a 7.5 minute digital elevation model

orientation parameters ($X_o, Y_o, Z_o, \omega, \phi, \kappa$) were determined by the solution of equation (1) for the photograph passpoints.

$$
\begin{aligned}
x &= -f * \frac{m_{11}(X_p - X_o) + m_{12}(Y_p - Y_o) + m_{13}(Z_p - Z_o)}{m_{31}(X_p - X_o) + m_{32}(Y_p - Y_o) + m_{33}(Z_p - Z_o)} \\
y &= -f * \frac{m_{21}(X_p - X_o) + m_{22}(Y_p - Y_o) + m_{23}(Z_p - Z_o)}{m_{31}(X_p - X_o) + m_{32}(Y_p - Y_o) + m_{33}(Z_p - Z_o)}
\end{aligned} \qquad (1)
$$

where:

x, y	are photo coordinates in the fiducial system;
X_p, Y_p, Z_p	are passpoint ground coordinates;
X_o, Y_o, Z_o	are camera station coordinates in ground system;
$m_{11}, m_{12}, \ldots, m_{33}$	are rotation matrix elements which are functions of ω, ϕ, and κ; and
f	is the known camera focal length

The coordinates (lines and samples) of the fiducials in the raster image were determined. These coordinates were found by measuring their location on an image display device. (This step is not necessary if the scanner is registered to the fiducials.)

The photo coordinates were referenced to the camera fiducial coordinate system using the linear conformal transformation equation (2).

$$
\begin{aligned}
x_c &= a x_r - b y_r + c \\
y_c &= b x_r + a y_r + d
\end{aligned} \qquad (2)
$$

where:

x_c, y_c	are calibrated fiducial coordinates;
x_r, y_r	are fiducial coordinates in the raster image (line and sample); and
a, b, c, d	are linear transformation parameters.

The first two profiles of the DEM were input to form a profile pair of DEM cells. The photo coordinates of the corners of each DEM cell in the profile pair were calculated using the previously determined parameters of exterior orientation. This calculation determined the number of lines of image data that were required to rectify the area between profiles.

The microdensitometer coordinates of the cell corners were computed using the photo coordinates, the linear transformation parameters, and the linear conformal transformation equations. This step was completed for each DEM cell in the profile

pair. The required number of lines of image data were then read into computer memory.

The cell was partitioned to the desired resolution. For a resolution of 2 m on the ground, the 30 m DEM cell was divided into 15 by 15 or 225 subdivisions. For NAPP imagery at 1:40,000 scale this gives a pixel size of 50 microns.

The elevation of the subdivisions were calculated from the surrounding area using bilinear interpolation. After interpolation the collinearity equations were again used with the previously calculated orientation parameters and the easting and northing of the ground point within the DEM cell were determined to compute the photo coordinates of the subdivision. Photo coordinates were computed in this manner for each subdivision within the DEM cell.

The photo coordinates were referenced to the camera fiducial coordinate system and so the linear transformation parameters used to compute the line and sample of the raster image correspond to the photo coordinate. For each cell subdivision the 8-bit binary gray scale value that corresponds to the image coordinate was assigned to the subdivision image coordinate. Choosing a gray scale value to be moved from the input image file to the output image file was accomplished by image resampling. Currently both nearest-neighbor resampling (using integer truncation to select the pixel) and cubic-convolution resampling (using a weighted average of neighboring pixels) are available.

The accuracy of the rectification process was measured by ascertaining the pixel coordinates of the passpoints appearing on the digital image and transforming them to their known positions. The passpoint locations in the orthophoto image were measured on a comparator, or image display device, and transformed to ground coordinates. The accuracy of the rectification was determined by comparing these measurements. A least-square fit of 33 test points measured for the McCall, Idaho, digital orthophotoquad showed the overall vector residual error to be 3.895 m, well within the map accuracy requirements for 1:24,000-scale mapping.

DIGITAL MOSAICKING OF ORTHOPHOTOS

Aerial photographs acquired under the NAPP are quarterquad centered. To produce a digital orthophotoquad complementing the 1:24,000-scale map series, digital mosaicking techniques must be used to join the digital orthophotos. This process removes the geometric and brightness discontinuities along mosaic seams. Because the images have been geometrically rectified to the desired map projection, the goal of the mosaicking process is to retain the geometric accuracy obtained during rectification while removing the small, but esthetically objectionable, discontinuities along the mosaic seams.

Four basic concepts were involved in the development of the Large Area Mosaicking System (LAMS). The first concept involves the use of carefully defined polygons inside the border of each image. These polygons define the location of the mosaic seams, determine where the automatic correlation routine is applied to produce seam control

points (points for which line and sample coordinates are known in two adjacent images), and limit processing to the portion of the scene included in the mosaic space. The second concept involves the adjustment of seam control points according to geographic control. Geographic control consists of points for which both the image line and sample and the geographic coordinates are known. The third concept involves the use of a compound geometric distortion model that corrects for lower spatial frequency distortions represented in the geographic control points, as well as the higher spatial frequency distortions represented by the seam control points. The fourth concept involves obtaining brightness correction information from the seam control points for use in adjusting brightness differences between adjacent images (Zobrist and others, 1983). Another very important aspect of LAMS is the use of a data base system to manage the large amounts of tabular data generated in support of digital mosaicking. Digital mosaicking is divided into two general processes - - the geometric correction process and the radiometric or brightness correction process.

Geometric Correction of Rectified Aerial Photographs

The first step in preparing a digital mosaic involves the selection of geographic control points. Because the individual digital orthophotos were geometrically rectified, the geographic control points are represented by a set of interior points used to hold the internal geometry of the images constant while removing the higher frequency geometric discontinuities along the mosaic seams. The passpoints used in the rectification process were used for geographic control points because they were well distributed throughout the images, and geographic and image coordinates were known.

The second step in the geometric correction process involves the selection of the polygonal boundaries for each image. As stated earlier, the polygons determine the location of the mosaic seams and seam control points while limiting processing to the portion of each image to be included in the final mosaic. The polygonal boundaries were manually selected using an image display device.

When working with digitally rectified aerial photographs, the selection of the polygonal boundaries is complicated by the spatial resolution of the data and the effects of look-angle. The polygons must be selected in such a way as to ensure that the effects of look-angle are minimized. For example, the polygon should not be selected through an area that is heavily shadowed in one image and not in the other.

Seam control points are located by applying a fast fourier transform (FFT) phase correlation along the polygonal boundaries. The correlation involves extracting image windows about the predicted seam control point from each image and running a phase correlation on the two image windows. The seam control point location in the second image is gradually changed until the best correlation value is found. To avoid false correlations, care must be taken in the selection of the correlation window sizes. The spatial resolution of the digitally rectified Portland photograph is approximately 1 m. Periodic features (more than one road intersection) frequently occur if the correlation windows are too large. For each successful correlation the line and sample locations for

both images and the correlation values are stored in the respective control point files.

The seam control points are edited on the basis of a first-order fit of all points for a common overlap area (seam control for image one and two are edited separately from seam control for image one and four). The magnitude of the acceptable residuals are based on the geometric accuracy of the digital orthophoto images as measured by the passpoints. In the case of the Portland mosaic residual errors as high as 4 pixels (4 m) were accepted.

After editing, the seam control points are adjusted to ensure an identical mapping to output line and sample in adjacent images. The adjustment process reconciles the differences in mapped line and sample of the seam control points by averaging. The geometric correction model for each image is based on the geographic and the seam control points.

Most geometric correction models designed for rectifying image data make use of polynomials or satellite spacecraft and sensor models, which are adequate for correcting single image distortions. When rectification is used to mosaic adjacent images, a surface interpolation method that is continuous, and yet can respond to the higher frequency distortions represented by the dense collection of seam control points is required (Thormodsgard and Lillesand, 1987). The LAMS incorporates a triangulation technique developed by Manacher and Zobrist (1978) to combine the internal geographic control points and the seam control points in the creation of the surface interpolation model, known as the finite element technique. Zobrist and Manacher made use of the "greedy" triangulation technique in which edges are added to the triangular network based on their length. After ordering the edges from shortest to longest, edges are added to the triangulation network so long as they do not intersect existing edges in the network. Figure 2a illustrates geometric and seam control points used for Photo 14 of the Portland orthophotoquad. The resulting triangulation network is depicted in figure 2b. Because direct application of this faceted surface is far too inefficient and computer-time-consuming for large data sets, the faceted surface is gridded or sampled by placing an evenly spaced rectangular grid over the surface to reduce the computation time and optimize computer resources during image resampling (Zobrist, 1982).

During the resampling process, the input image space is mapped into the output image space. At each grid intersection this mapping is exact, at other locations bilinear interpolation within the grid cell is used to locate the input pixel. Currently a cubic convolution resampling algorithm is used for calculating the output pixel value. An assessment of the geometric accuracy of the transformed images verified that the goal of maintaining the accuracy of the digitial orthophotos was met. Table 1 shows the predicted and measured passpoint locations of photo 14 before and after image transformation for mosaicking.

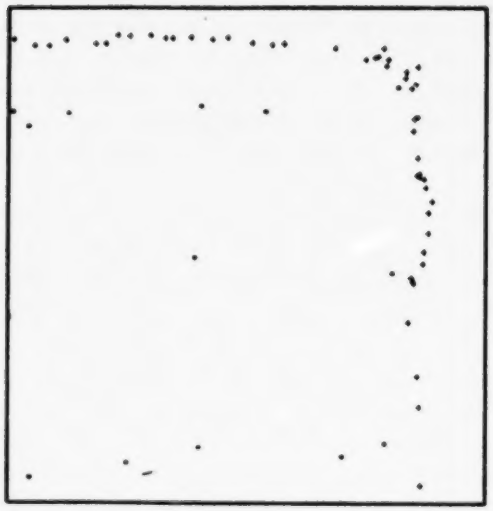


Figure 2a. - - Geometric and seam control for photo 241

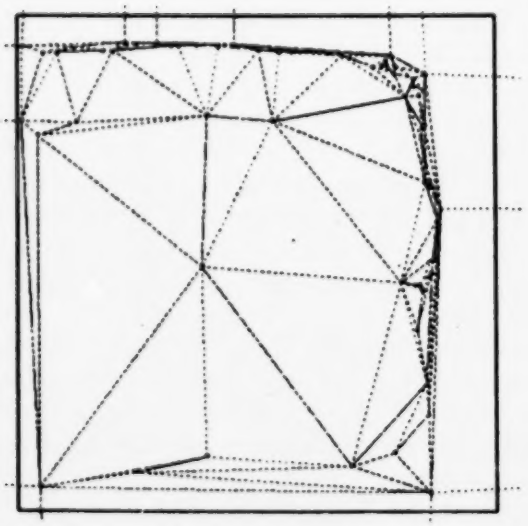


Figure 2b. - - Faceted surface resulting from triangulation of geometric and seam control points

/...

Table 1. - - Photo 14 passpoint locations after rectification and mosaicking

POINT NUMBER	PREDICTED		AFTER RECTIFICATION		AFTER TRANSFORMATION	
	Line	Sample	Line	Sample	Line	Sample
10030	160	158	160	165	157	159
10032*	1959	526				
10033	2079	180	2079	183	2079	182
10040*	168	158	167	1967		
10042	1941	2295	1940	2297	1939	2296
10050	467	3844	470	3846	469	3847
10052	1990	3673	1993	3676	1994	3678
10401*	1733	3500				
10411*	1894	1707				
10421*	1946	41				

* Point was unidentifiable due to image resampling.

Radiometric Correction and Mosaicking of Rectified Aerial Photographs

After all geometric corrections were applied and the geometric accuracy verified, the images were radiometrically matched and mosaicked. Working two images at a time, brightness correction information was collected along the polygonal seam boundary of the add-on image. The average pixel value for 10 by 10 pixel windows centered about the seam control points was computed for the reference and the add-on image and the information stored in tabular form. The average brightness difference between the two images was calculated. The remaining brightness differences were modeled using the gridded finite element technique discussed above, however during radiometric correction the surface reflects the brightness adjustment to be applied at each vertex of the resulting triangles. At each grid intersection the brightness mapping is exact; at other locations bilinear interpolation within the grid cell was used to approximate the brightness adjustment to be applied to the input pixel. The corrected add-on image was cut precisely according to the polygonal boundary defined, and the two images were mosaicked. The process was repeated for all subsequent images in the mosaic where the previously created mosaic was used for the brightness reference image. Brightness correction and mosaicking were repeated for all bands.

ENHANCEMENT OF DIGITAL ORTHOPHOTOS

To improve the appearance of the digital mosaic, enhancement techniques such as spatial filtering and contrast enhancement were applied to the image. A spatial filter was used to increase the effectiveness of the subsequent contrast enhancement process (Chavez, 1984). To increase the high-frequency component and sharpen the image an edge enhancement was applied to the data (Chavez and Berlin, 1984). This edge enhancement was accomplished by applying a small kernel (3 by 3 or 5 by 5) spatial filter to the image to increase the high-frequency spatial variation, thereby increasing the radiometric differences between pixels along edges. After filtering a multiple-point linear stretch was performed on each band. The cumulative histogram of each band was evaluated to determine the number and position of the breakpoints (Kidwell and McSweeney, 1984). The breakpoints were selected to provide a pleasing color product.

FUTURE RESEARCH

Additional research will be required to develop a digital orthophoto production system. Questions that must be answered include: DEM resolution for specific orthophoto scales, optimum image resampling, format of the digital data, distribution media, and optimum output medium.

Currently, the standard 30 m spacing of DEM is used during the rectification process of 1:80,000-scale NHAP and 1:40,000-scale NAPP images. For larger scale photography the 30 m cell spacing of the DEM is questionable. Continuing research will address the requirements for higher resolution DEM's.

Research has recently been completed to develop a modulation transfer function (MTF) deconvolution kernel for digitized aerial photography scanned on an Optronics C-4500 film scanner (Schowengerdt, 1988). The resulting kernel is then used in a table-lookup resampling algorithm to simultaneously restore and resample the processed imagery (Schowengerdt, 1988).

While the Optronics (essentially a whisk broom scanner) is similar to the Landsat MSS and TM and the AVHRR systems, operational differences dictated the decision to measure the MTF from special film targets scanned with standard instrument settings rather than attempting a detailed sensor model. Initial results suggest that MTF deconvolution can be applied to digitized aerial photographs resulting in significant visual enhancement, however the results are limited by film granularity and film tightness during scanning. Research will address the implementation of this work in the digital rectification process.

Research will be required to determine the media best suited for storing data sets the size of digital orthophotoquads (NAPP photography scanned at 50 micron results in approximately a 4,000 line by 4,000 sample image.) The Geological Survey is experimenting with storing the digital orthophoto in encoded format on a CD ROM. In addition the issue of data format must be addressed. The digital orthophoto will require a header file containing such information as: type of photography, geographic

coverage, type and quality of DEM data used, date produced, and accuracy assessment information.

APPLICATIONS

Presently the Geological Survey is exploring the utility of large scale orthophoto products as a base map component of a local multipurpose cadastre for city, county, and regional agencies. Pilot projects of the Fontana, California, and Portland, Oregon, areas have been started. In the Fontana project, as well as producing a 1:4,800-scale color infrared digital orthophoto, four 1:12,000-scale digital orthophotos were produced from 1:20,000-scale photographs. The four orthophotos were then digitally mosaicked to form a 1:24,000-scale orthophoto. In the Portland pilot project, 1:21,000-scale photographs were digitally rectified and mosaicked to create a 1:12,000-scale digital orthophoto. This orthophoto will be evaluated for use in field identification and classification, as well as for stereocompilation.

Other possible applications for digital orthophotoquads include: map revision, custom maps, and as a base layer in a geographic information system (GIS) environment. Once contours have been captured for a quadrangle, incorporation of stereoinstruments in the mapping process is limited to the need to view new imagery in stereo for correct planimetric placement of new features. With the capability to produce digitized orthophotos, interpretation of new imagery can take place on image display devices rather than on a stereoplotter. New features could be captured in digital form directly and incorporated into the National Digital Cartographic Data Base. The capability to digitally rectify and mosaic aerial photographs makes the production of customized maps possible. Customized image processing techniques can be applied to enhance features of interest to various disciplines, such as geology, hydrology, and resource management. The digital orthophoto in a GIS environment can be overlayed with vector data, such as boundary, hydrography, and vegetation indexes, and used for a broad range of analysis.

CONCLUSIONS

The Geological Survey has developed the capability to produce digital orthophotos high spatial resolution from scanned aerial photographs and DEM data. The accuracy is primarily limited by the quality of the DEM data used.

Once rectified, digital image processing techniques, such as mosaicking, contrast enhancement, and filtering, can be applied to improve the usefulness of the data. The capability to mosaic digital orthophotos provides the means to join not only images within a quadrangle but also to join adjacent quadrangles. Attention is being directed toward improving the efficiency of the techniques and designing a production system. Although much work remains, the digital orthophoto offers great potential to computer-aided cartography.

REFERENCES

Chavez, P.S., 1984, Digital processing techniques for image mapping with Landsat TM and SPOT simulator data: Proceedings of the 18th International Symposium on Remote Sensing of the Environment, Paris, France, October 1-5, 1984, pp. 101-116.

Chavez, P.S., and Berlin, G.L., 1984, Digital processing of SPOT simulator and Landsat TM data for the SP Mountain Region, Arizona: SPOT Simulation Applications Handbook, Proceedings of the 1984 SPOT Symposium, Scottsdale, Arizona, May 20-23, 1984, ASPRS, pp. 56-66.

Horton, J., 1978, The PDS differential rectifier: an economical approach to digital orthophotos: Applied Optics Division, Perkin-Elmer Corp., Garden Grove, California, pp. 1-10.

Keating, T.J., and Boston, D.R., 1979, Digital orthophoto production using scanning microdensitometers: Photogrammetric Engineering and Remote Sensing, Vol. 45, No. 6, pp. 735-740.

Kidwell, R.D., and McSweeney, J., 1985, Art and science of image maps: Proceedings of the 51st Annual ASP Meeting, Vol. 2, Washington, D.C., March 11-15, 1985, pp. 770-782.

Konecny, G., 1976, Mathematical models and procedures for the geometric restitution of remote sensing imagery: Proceedings of Commission III of the XIII Congress of the International Society for Photogrammetry, Helsinki, Finland, 1976, pp. 20-24.

Konecny, G., 1979, Methods and possibilities for digital differential rectification: Photogrammetric Engineering and Remote Sensing, Vol. 45, No. 6, pp. 727-734.

Manacher, G.K., and Zobrist, A.L., 1978, A fast, space-efficient average-case algorithm for the "greedy" triangulation of a point set, and a proof that the greedy triangulation is not optimal: Proceedings of the 16th Annual Allerton Conference on Communication, Control, and Computing, Monticello, Illinois, October 4-6, 1978, pp. 824-832.

Olsen, R., 1984, Digital orthophoto concept: Unpublished notes presented to technical staff, Western Mapping Center, U.S. Geological Survey.

Schowengerdt, R.A., 1988, Research in restoration of digitized aerial photography: Final Report to the EROS Data Center, Cooperative Agreement No. 14-08-0001-A-0330, University of Arizona, August 1988.

Thormodsgard, June, and Lillesand, Thomas, 1987, Comparison of the gridded finite element and the polynomial interpolations for geometric rectification and mosaicking of Landsat data: Proceedings of ASPRS-ACSM Annual Convention, Vol. 2, Baltimore, Maryland, pp. 139-151.

Wolf, R., 1974, Elements of photogrammetry (2d ed.): McGraw-Hill, Inc., New York, pp. 60-64.

Zobrist, A.L., Bryant, N.A., and McLeod, R.G., 1983, Technology for large digital mosaics of Landsat data: Photogrammetric Engineering and Remote Sensing, Vol. 49, pp. 1325-1335.

Zobrist, A.L., 1982, Computation aspects of remapping digital imagery: Proceedings of NASA Workshop on Registration and Rectification, Leesburg, Virginia, November 17-19, 1981, pp. 358-370.

UNITED
NATIONS

E

Economic and Social Council

Distr.
LIMITED

E/CONF.83/L.35
21 January 1991

ENGLISH ONLY

TWELFTH UNITED NATIONS REGIONAL
CARTOGRAPHIC CONFERENCE FOR
ASIA AND THE PACIFIC
Bangkok, 20-28 February 1991
Item 7 (b) of the provisional agenda*

CARTOGRAPHIC DATA RETRIEVAL, ANALYSIS, DEPICTION, PRESENTATION AND PRODUCT GENERATION: DIGITAL DATA BASES

The United States Geological Survey-United States Bureau of the Census cooperative digital mapping project: A unique success story

Paper submitted by the United States of America**

---

* E/CONF.83/1.

** Prepared by Bruce Y. McKenzie, United States Geological Survey and Robert A. LaMacchia, United States Bureau of the Census.

Between December 1983 and June 1987, the U.S. Geological Survey (USGS) and the U.S. Bureau of the Census (Census Bureau) cooperated to establish a 1:100,000-scale transportation and hydrography digital data base. The magnitude of the task of converting to digital data the transportation and hydrography information contained on 1,823 1:100,000-scale quadrangles and the short timeframe for accomplishing this project required the development and implementation of state-of-the-art digital production systems in both agencies. The completed 1:100,000-scale digital data files are now part of the National Digital Cartographic Data Base (NDCDB) maintained by the USGS. The USGS distributes these files as U.S. GeoData 1:100,000-scale Digital Line Graphs (DLG's). The transportation and hydrography data are being distributed in 30- by 30-minute blocks. These 30- by 30-minute areas correspond to the east or west halves of the 1:100,000-scale maps. These data are topologically structured, attribute coded and available in standard and optional DLG format. Because 1:100,000-scale DLG's have a topologically structured format in which relationships among features are encoded, the data can be used for general spatial applications, to perform statistical calculations, or for tabulations.

The Census Bureau is using the 1:100,000-scale transportation and hydrography digital data as the cartographic base for their Topologically Integrated Geographic Encoding and Referencing (TIGER) System, which covers the Nation, Puerto Rico, Virgin Islands, and outlying areas of the Pacific. The Census Bureau has added information such as feature names and political and Census statistical boundaries and codes to the TIGER files for use in the 1990 decennial and subsequent economic censuses and surveys. For the 1990 decennial census alone, the Census Bureau will produce over 2 million individual map sheets from these data.

The joint venture between the USGS and the Census Bureau has great economic significance. The 1:100,000-scale digital cartographic data base combines the qualities of sufficient detail, adequate content, and nationwide coverage that will allow and encourage increased use of spatial analysis methods. For example, after 1990, the data reported by the Census Bureau from the 1990 decennial census can be related to features included in the 1;100,000-scale data base. The USGS and the Census Bureau are making all of these data available through both agencies' information outlets. This compatibility of census data with the USGS digital cartographic data base can only be of increased benefit to all Federal, State, local, and private users.

THE U.S. GEOLOGICAL SURVEY-U.S. BUREAU OF THE CENSUS COOPERATIVE DIGITAL MAPPING PROJECT: A UNIQUE SUCCESS STORY

THE BEGINNING

Initial Test Project

The need for a digital cartographic base as the "heart" of the Census Bureau's full range of cartographic and geographic support processes necessary to serve the data collection, tabulation, and dissemination needs of the 1990 decennial census, led the Census Bureau to begin discussions with the USGS. These discussions led to the formation of an interagency task force and initiation of test projects to determine the feasibility of building the required digital data base.

With the formation of the interagency task force in 1981, the USGS and the Census Bureau wanted to answer the question of comparability of between a digital cartographic file based upon digitizing the 1:24,000-scale map sheets and a digital cartographic file based upon the 1:100,000 map sheet. Two 1:100,000-scale map sheets were selected for the test: the USGS raster-scanned the map sheets and created vector files, and the Census Bureau manually digitized the corresponding 1:24,000-scale map sheets using it's Intergraph equipment. The USGS provided the 1:100,000-scale vector file to the Census Bureau which then plotted the data from the two separate files in different colors at the 1:24,000-scale. This test showed that the 1:100,000-scale data compared favorably at the 1:24,000-scale and could be further enlarged and used to produce maps for enumerator use.

This test only answered the first question--that data digitally captured from the 1:100,000-scale maps could be used to produce an acceptable large-scale map. The question which remained to be answered was whether the USGS and the Census Bureau could undertake this process for the entire Nation. The two agencies decided to undertake a pilot project to answer this second question.

Florida Pilot Project

In early 1983, a cooperative digital pilot project was begun to collect and process the transportation and hydrographic data shown on the 48 1:100,000 scale maps that cover the State of Florida. The purpose of the project was to enable the USGS to develop and test new production procedures and software, to incorporate the Scitex Response scanning and editing system into its current digital production system, and to enable the Census Bureau to develop the necessary software and production, procedures to encode and structure data for incorporation into the National Digital Cartographic Data Base. This pilot project was designed with (1) the USGS performing the initial collection and processing of all transportation and hydrographic information using the Scitex system, (2) the Census Bureau performing all attribute coding and structure of the roads data, (3) the USGS performing all the attribute coding and structuring of the hydrographic and other transportation data, and (4) the USGS performing final data verification, testing, and

/...

storing, of the information. Each phase of this project provided valuable insight on data gathering and processing procedures. It also provided data sets for evaluation and testing by both agencies.

The Official Start

The results of this pilot project led to the commitment by both agencies, through an agreement signed in December 1983, for completion of a conterminous U.S. 1:100,000-scale transportation and hydrography digital data base by mid-1987. To meet the deadline, both agencies proceeded with the implementation of complementary 1:100,000-scale digital production systems. The data digitized to build this data base were all the transportation (roads, railroads, powerlines, pipelines, and airports) and hydrographic (streams, rivers, water bodies) features shown on the 1,823 1:100,000-scale quadrangles covering the conterminous United States.

PRODUCTION SYSTEMS--AGENCY RESPONSIBILITIES

The production procedures and software that were developed as a result of the cooperative pilot project for the State of Florida have been described in considerable detail in other papers. The following paragraphs summarize the production process during the project, which improved the quality of the data and resulted in efficiencies in the data collection procedures.

Base Map Operations

The fundamental graphic product required for digital data collection was the USGS 1:100,000-scale map series. The framework and content of the 1:100,000-scale base map is derived primarily from 1:24,000-scale maps, with updates during the production process. This production process generally has the following phases: (1) reducing larger scale maps to 1:100,000-scale and mosaicking on the Universal Transverse Mercator projection, (2) updating the mosaicked base, (3) scribing the planimetric feature separate manuscripts, (4) scribing the contour manuscript, and (5) printing the complete topographic edition.

Since the 1:100,000-scale mapping program began in 1976, the map series has been predominately topographic contour editions. When the cooperative digital project began in December 1983, only 960 of the required 1,823 maps were available for digitizing. In order to ensure that the remaining base maps were available for digitizing, emphasis was shifted from preparing topographic editions to producing planimetric bases without contours. This compilation change coupled with increased personnel resources enabled conterminous U.S. coverage to be achieved in October 1986; 5 years ahead of the original mapping goal.

Digital Operations

As mentioned previously, in order to meet the mid-1987 deadline, complementary high-volume digital production systems were established in each agency. The USGS had

dedicated to this project effort, 2 Scitex scanners; 15 Scitex R-280 editing stations; 26 Intergraph Interactive editing/tagging stations; 13 Altek digitizing tables; and 4 Gould 9780 minicomputers. This equipment was dispersed among four regional mapping centers: Eastern Mapping Center in Reston, Va., Mid-Continent Mapping Center in Rolla, Mo.; Rocky Mountain Mapping Center in Denver, Colo.; and Western Mapping Center in Menlo Park, Calif. The Census Bureau employed the use of a Sperry 1100/74 and subsequently a Sperry 1100/92 mainframe computer. Connected to these computers were 18 Tektronix 4115 computer graphic terminals (later upgraded to Tektronix 4125 terminals) located at the Census Bureau in Suitland, Md., and an additional 8 Tektronix 4115/4125 terminals located in the Census Bureau's Boston Field Digitizing Site.

Each agency staffed most of this equipment in three 8-hour shift operations per day. The USGS had the responsibility for digitizing all transportation and hydrographic features and assigning feature classification codes to all data except roads; the Census Bureau had the responsibility for assigning feature classification codes to the road data.

Two basic production procedures were used by USGS to capture the data: manual digitizing and automated scanning techniques. Due to lack of density, the miscellaneous transportation data (pipelines, powerlines, airports, etc.) were digitized using manual line-following techniques, subjected to both manual and computer editing, processed through topologic structuring software, and archived. The hydrography and road files were typically much more dense and complex. They were, therefore, scanned by machine; edited via both batch and interactive procedures; and through software, converted from raster to vector data. At this point the hydrography and roads categories took two separate processing paths. The hydrography data were tagged with appropriate attribute codes and further edited using interactive graphic systems by the USGS. The road data was sent to Census for attribute tagging geometric corrections, and then returned to USGS for review and acceptance.

Following the completion of the editing and tagging operation, both data sets were processed through the Unified Cartographic Line Graph Encoding System (UCLGES) or more recently the DLG Production System (PROSYS) software resident in each production center. These systems perform all final data structuring and verification of DLG files. Both systems also perform several logical checks to verify topology and the proper use of attribute codes. Errors were corrected either through a batch editing routines or the data sets were returned to the producer (USGS or Census Bureau) for correction. When a file was completely verified, the files were archived and prepared for delivery to the Census Bureau.

At this juncture, both categories for each 30- by 60-minute quadrangle were delivered on tape to the Census Bureau where a final check was conducted to ensure that both categories were internally consistent. This check was accomplished using software that first horizontally integrated the individual 7.5-minute quadrangle data files that comprised each 30- by 60-minute quadrangle, and then vertically integrated the four resulting data files to create a single topological file in a preliminary TIGER structure. After successfully passing this final check, the 1:100,000-scale digital data were archived by USGS for sale to the public through the National Digital Cartographic Data Base (NDCDB).

Problems Related to File Production

The project was not without problems. Just ironing-out the logistics associated with the transfer of data and materials between the two agencies, and even within each agency, created some complex and sensitive situations. In addition to the general problems associated with expediting the production of the 1:100,000-scale graphics, there were numerous technical problems that arose in establishing a digitizing, editing, and processing routine to convert these graphics into digital form. These issues can be grouped into two primary areas: (1) data problems and (2) quality-control procedures. The area of data problems includes four categories:

1) System implementation - problems introduced due to techniques and software development during the initial stage of the project, and primarily involved developing and adapting software for utilization on different versions of the same equipment.

2) Data Processing - problems introduced due to clerical errors and miskeying of input data.

3) Interpretation - problems introduced due to operator misunderstanding of attribute coding standards or map symbology.

4) Geometric - problems introduced by system digitizing and processing routines and resulted in the automatic generation of extraneous lines and gaps in line segments.

The first three categories were short-term problems that eventually disappeared with the increasing experience of personnel and stabilization of the production process. The fourth category, geometric problems, was the area where the most effort was expended for resolution. New software had to be developed and procedural changes in both agencies were required. In some instances, completed data sets had to be reprocessed and reverified.

Since 1:100,000-scale digital data comprised a new product, the establishment of quality-control procedures was essential to insure that the final product met not only the needs of the Census Bureau but also met the Geological Survey standards for entry in the NDCDB. Several procedures were adopted to minimize the potential for occurrence of errors in data. The most significant was the implementation of a criteria for verification and acceptance of corrected and tagged road data. Quality-control procedures included a recheck for all attribute codes for randomly selected sections of a 1:100,000-scale quad; the use of topology-verification software routines; visual inspection of plots to check the digital data against the graphic; and a final delivery acceptance/check of each data set (hydrography and transportation) performed by the Census Bureau through a process called horizontal and vertical integration of the data.

CENSUS BUREAU USE OF THE DIGITAL DATA

The Census Bureau is using the digital data from this cooperative project, as the "heart" of a bold new system to modernize its cartographic and geographic processes. This new data base, called the TIGER System, will support the Census Bureau's future demographic and economic data collection, processing, and tabulation activities, beginning with the 1990 decennial census. To use the 1:100,000-scale digital data for this purpose, the Census Bureau enhanced and reformatted the USGS DLG data to support its field and processing operations. This involved completing seven major tasks:

1. The Census Bureau's Geography Division vertically integrated the four separate data categories for each 1:100,000-scale map in an automated process that determines where the hydrographic, railroad, and miscellaneous transportation features intersect the road features and each other. This process results in a single topological data base where a Census Bureau feature class code identifies each line and a numeric code identifies each area enclosed by a set of lines.

2. While the process of building the digital file was underway, the Census Bureau's 12 regional office geographic staffs compiled map update information on 1:24,000-scale USGS map sheets using sources gathered from local government officials. These new features included roads, railroads, and hydrographic features. Appended to each feature, both old and new, was a key number that represented the name of the feature where the geographic staff could determine the name. Where multiple names were known, one name was designated as the primary name and all others were designated as alternates.

3. The Census Bureau created individual 7.5-minute files from the topological data base for use on their standalone microcomputers in four Field Digitizing Sites (FDS) in Boston, Atlanta, Dallas, and Denver. The data were downloaded from the Sperry mainframe computer to 8-inch floppy disk's for use in the Tektronix 4125 microcomputer graphic workstations. The FDS staff updated the digital file based upon the information posted to the 1:24,000-scale maps; this update included the new features and feature names. A total of 60 Tektronix 4125 microcomputer graphic workstations were used for this work. The updated files were returned on 8-inch floppy disk's to the Geography Division where the files were uploaded to the Sperry for further processing.

4. Staff in the Census Bureau's Data Preparation Division in Jeffersonville, Ind., annotated maps, primarily using USGS quadrangles, showing the 1980 census geographic area boundaries. The geographic area boundaries and codes shown on these maps were entered by Census Bureau staff, using an additional 20 Tektronix 4125 microcomputer graphic workstations, in Jeffersonville, Suitland, and the four Field Digitizing Sites into the growing preliminary TIGER data base. Again, the file transfer between these sites and the Sperry computer was by 8-inch floppy disk.

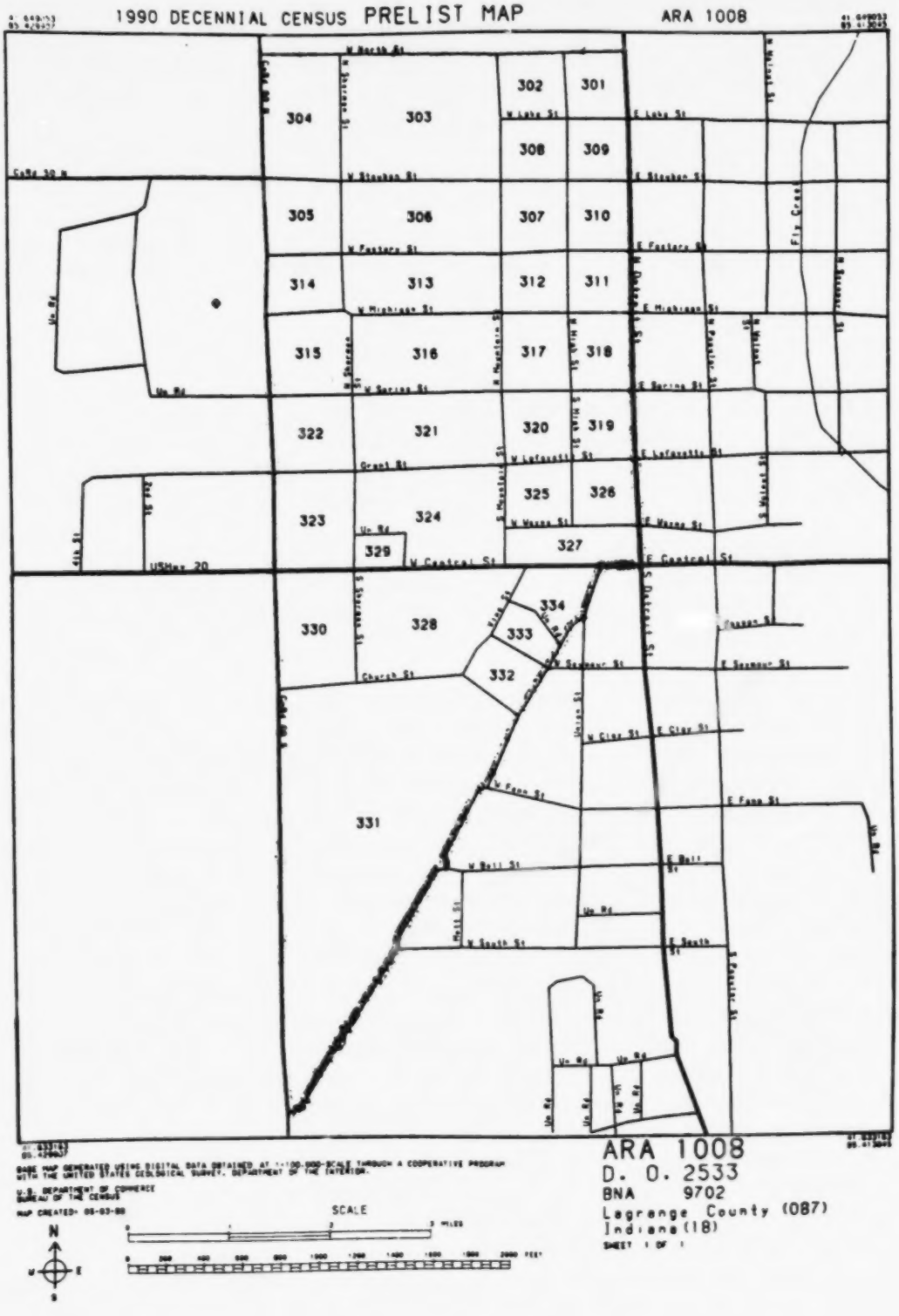
/...

5. Once the 1980 census geographic area codes were in the preliminary TIGER data base, the separate 7.5-minute files were horizontally integrated. During this step, all of the 7.5-minute "cells" that comprise a county are put together into a single file and all lines that cross a cell boundary are edge matched. Once the horizontal integration is complete, the county file is created by "trimming" away all of the polygons that are outside of the county. The outer edge of this file is now fixed for the duration of the census to ensure that adjacent files exactly match.

6. Using copies of maps produced from the county files, the geographic staff in the Census Bureau's 12 regional offices annotated the 1990 census "collection" geographic area boundaries delineated by local statistical area committees and State agencies. Staff in the Geography Division and the Boston and Denver FDS's added these additional geographic area codes to the data base for use in collecting 1990 census data. These geographic areas include census tracts and block numbering areas, block groups, and American Indian reservations. The computer assigns the 1990 census block numbers to all blocks in the country based upon an algorithm that uses the feature class code of the bounding line segments and the size of the polygons.

7. Finally, to tabulate and present the results of the 1990 decennial census, the Census Bureau added the 1990 geographic area boundaries and identification codes for statistical areas such as Census Designated Places, and Census County Divisions. The Census Bureau also corrected the political boundaries in the TIGER file to represent the January 1, 1990 Boundary and Annexation Survey (BAS). The Census Bureau conducts the BAS annually, and beginning with the 1988 BAS, sent local governments a map of their governmental unit plotted from the TIGER file. The local official used this in reviewing their boundaries and for showing the new boundaries caused by annexations or detachments.

In October 1987, the Census Bureau began the production of over 250,000 individual map sheets for the approximately 82,000 enumeration areas (block groups) from which the Census Bureau field staff created address lists for use by enumerators performing preliminary field work during the summers of 1988 and 1989. These maps were plotted on electrostatic plotters. (A sample section from an enumerator assignment map produced from the TIGER File appears as figure 1.) The Census Bureau prepared these map products using a totally automated production system that determines the scale of each map based upon the features to be displayed for the particular area. This mapping software also automatically determines when to produce "inset" sheets for areas of congested street pattern; places all of the text (street, river, and railroad names); and places all of the geographic area codes such as the block numbers in the appropriate polygons. When necessary, the mapping software determines if a feature name needs to be displayed more than once, if any census block needs "fishhooks" (a line connecting two blocks indicating that the adjacent block has the same block number), displays landmark symbols, and generates related marginal text, including map identification numbers, a map sheet index (if required), State and county names and codes, and a bar code representing the map identification information in machine-readable form.


1990 DECENNIAL CENSUS PRELIST MAP
ARA 1008
W Berrick St
E Lake St
W Lake St
E Stanton St
W Stanton St
E Fostoria St
W Fostoria St
E Michigan St
W Michigan St
E Perry St
W Perry St
E Barnes St
W Barnes St
E LaFayette St
W LaFayette St
E Wayne St
W Wayne St
E Central St
W Central St
Grant St
Church St
Union St
E Clay St
W Clay St
E Pane St
W Pane St
E Bell St
W Bell St
E South St
W South St
Mill St
S Detroit St
S Public St
S Wayne St
S Main St
S Meyer St
S Spring St
S Forrest St
Fly Creek
US Hwy 20
Un Rd
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
ARA 1008
D. O. 2533
BNA 9702
Lagrange County (087)
Indiana (18)
SHEET 1 OF 1
SCALE
N
W
E
S

/...

The Census Bureau estimates that before the 1990 census is over, it will produce over 2 million individual map sheets on their electrostatic plotters. All of these maps will be plotted without manual intervention. The only human involvement is the submittal of the computer processing runs; the mounting of tapes on the computers and electrostatic plotters, and cutting the map sheets as they come from the plotter.

AVAILABILITY AND DISTRIBUTION OF DATA

On August 4, 1987, the two agencies announced plans for the cooperative promotion of their products resulting from this project at the annual meeting of the Urban and Regional Information Systems Association. These products, known as US GeoData (for DLG's) and TIGER data respectively, can be ordered from either agency. Both agencies have information regarding the complete set of products available from this effort.

The Census Bureau completed release, in April 1989, of the first public product from the TIGER data base--the TIGER/Line file. This product is being made available in four versions: Prototype (available April 1989), Precensus (available February 1990), with Initial Voting District Codes (available October 1990), and the 1990 Census (available beginning in January 1991 with the last files released by the end of March 1991). The price for these files is based on the number of counties purchased at one time within a single state; the price varies with the version of the TIGER/Line file. The Precensus TIGER/Line file is $200 for the first county in a state and $25 for each additional county in the state ordered at the same time.

The Census Bureau expects to release additional extracts from the TIGER file in 1991 after the completion of the census. These additional extracts will include the TIGER/Data Base, an extract file that will contain the most complete set of releasable geographic and cartographic data possible in standard interchange format; TIGER/Comparability, an extract file that will contain records that equate 1980 census tracts to 1990 census tracts; TIGER/Boundary, extract files that contain coordinate data for several specific boundary sets such as county and census tract boundaries; and TIGER/GICS, a file providing the name and some related status codes for each geographic area for which the Census Bureau tabulated data in the 1990 Census.

On July 15, 1986, the USGS began distribution of US Geodata Digital Line Graphs from 1:100,000-scale maps. All the transportation and hydrography digital data collected from 1,823 1:100,000-scale quadrangles are available through the USGS NDCDB. The 1:100,000-scale DLG's are topologically structured, attribute coded, and available in standard DLG format (has an internal file coordinate system) or optional DLG format (has already been converted to Universal Transverse Mercator coordinates.) Data on transportation and hydrography are presently distributed in two packaged versions. In the first (preliminary) version, the 7.5-minute files (except for railroad, pipelines, and power lines, which were digitized and are distributed as 30-minute files) are not edge-matched but are made available for each 30- by 30-minute area of coverage (east or west halves of the 1:100,000-scale maps). For each 30-minute block, the two categories of data--hydrography and transportation--are sold separately. All hydrography (flowing water, standing water, wetlands) data is contained in one file; transportation data is contained

in three separate files (1) roads and trails, (2) railroads, and (3) pipelines, transmission lines, and airports. For the second (final) distribution version, the aforementioned 7.5-minute files have been processed through paneling, partitioning and edge-matching software and are produced and distributed as four 15- by 15-minute files for each 30- by 30-minute block, except in high-density areas, where the 15-minute file size precludes the joining the 7.5-minute files. The process of repackaging results also in a 30- by 30-minute unit of railroads or miscellaneous transportation data being partitioned into four 15- by 15-minute data files. As data sets are paneled and partitioned into 15-minute blocks, they are replacing those 1:100,000-scale 7.5-minute files currently in the NDCDB. This paneling and partitioning process is complete for 60% of the 1:100,000-scale files. The price for each 30- by 30-minute area of coverage is dependant upon the total number of 30-minute block units purchased. If 6 or more units are being purchased, the cost is a base charge of $90 plus $7 for each additional sales unit.

APPLICATIONS/FUTURE DIRECTIONS

The USGS and the Census Bureau serve rather different markets. The Census Bureau serves customers interested in portraying political and statistical areas, producing thematic maps based on 1990 census information, performing density calculations, and undertaking other related statistical data analysis. The USGS serves customers needing base map digital data and those customers who perform automated integration of spatial data with natural resource data bases in geographic information systems (GIS).

In the area of GIS's, both agencies are paying attention to the future direction and the future challenge of the joint effort. The USGS is making considerable effort to explore innovative GIS applications of spatial data bases, and also is continuing to expand the contents of the 1:100,00-scale digital data base by adding Public Land Survey System, boundaries, and hypsography digital data. The 1:100,000-scale base categories of digital data are especially well suited for regionally based applications such as mineral resource analyses, hydrologic analysis, and regional planning, within a GIS environment. The addition of Census Bureau information in the 1990's will allow spatial analysis of vast amounts of socioeconomic data and may serve as a catalyst for the widespread use of GIS technology in the United States.

CONCLUSION

The U.S. Geological Survey and the Census Bureau reached a major milestone with the completion of their cooperative project to develop a 1:100,000-scale transportation and hydrography digital data base for the United States. Reaching this milestone provides the map user community with a significant new product: 1:100,000-scale digital data for the roads, hydrography, railroads, and miscellaneous transportation features shown on the printed 1:100,000-scale maps. The nationwide digital data coverage at this scale combines the qualities of sufficient detail, and adequate content, that can serve as a framework for use in geographic information systems. The compatibility of census data with USGS digital cartographic data can only offer increased benefit to all federal, State, local, and private users.

UNITED
NATIONS

E

Economic and Social Council

Distr.
LIMITED

E/CONF.83/L.36
24 January 1991

ENGLISH ONLY

TWELFTH UNITED NATIONS REGIONAL
CARTOGRAPHIC CONFERENCE FOR
ASIA AND THE PACIFIC
Bangkok, 20-28 February 1991
Item 7 (b) of the provisional agenda*

CARTOGRAPHIC DATA RETRIEVAL, ANALYSIS, DEPICTION, PRESENTATION AND PRODUCT GENERATION: DIGITAL DATA BASES

Digital map data: A component of geographic and land information systems

Paper submitted by the United Kingdom of Great Britain and Northern Ireland**

* E/CONF.83/1.

** Prepared by M. Sowton, Head of Research and Development, Ordnance Survey, Southampton, United Kingdom and J. Price, Manager, Overseas Surveys Directorate, Ordnance Survey, Southampton, United Kingdom.

A map is essentially a compromise between scale, content and depiction, representing features in the terrain which have been surveyed, fair drawn and printed. Topographic maps are made for a variety of purposes and both content and scale are altered to fit the requirements of users. A map is of itself an information system containing a multitude of data which is transformed in the users brain into information.

With the advent of digital mapping techniques in the late 1960s it was anticipated that map production could be speeded up. What was not foreseen was the possibility that the data created for map production would be of value for other purposes.

By the 1980s the use of digital map data as a background for the display of map related information was rapidly increasing but at that time it was seldom required to support the analysis process.

The essential nature of a GIS is that it should be capable of linking data from various sources through spatial links contained in the data. Provided the spatial data also carries within it sufficient "intelligence" a computer system can use it to carry out analysis and make logical deductions. Improvements in the map data content has made this possible. LIS is defined in the paper as a subset of GIS.

Some examples of the way in which digital map data can be used in GIS/LIS applications are given.

Introduction

A conventional map is a sophisticated information system which has been measured by the surveyor, drawn by the cartographer and printed by the printer. Each works to a specification which determines the accuracy, the content and the area covered.

The specification determines which features in the terrain are selected and how they are measured, fair drawn and printed. Early cartographers embellished their work with pictorial symbols which represented significant features but whose main purpose was to overcome limitations of accuracy and content. By using designs to

fill the blank spaces surrounding the mapped area they produced an attractive result which was cartographically pleasing if metrically doubtful.

The scale of these early maps was determined to a great extent by the amount of detail to be shown and the positional accuracy of the survey had a lower significance than in modern cartography. Later, improvements in surveying techniques meant that more topographic detail could be measured and depicted accurately and the map scale took on more significance in the map design. As time passed the cartographer spent less time ornamenting his map and placed more emphasis on the correct depiction and placement of the topographic features.

As the ability of the surveyor to produce accurate positional surveys improved, the need for accurate large scale maps could be met. The cartographer was now faced with a dilemma; there was too much detail and the accuracy was greater than necessary for some of the map scales. Thus the cartographer had to develop rules which he applied to reduce the content and downgrade the accurate coordinates provided by the surveyor in order to produce smaller scale maps for specific purposes from larger scale surveys. This process, known as generalisation is a compromise between the map scale, the content and the way in which detail is depicted. For any particular map or more frequently map series, this compromise is arrived at by agreement between the map designers and the map users.

There is one further limitation imposed on the cartographic design and this is the sheet size. The sheet size is limited by the physical size which can be handled comfortably by the user, by storage considerations and to a limited extent by the size of the printing press. A number of standard printing sizes exist from which the map designer can select one which is suitable taking account of the effect upon ground coverage at the scale selected, sheet layout and design of the map series.

A map is an information system

The information content of any map depends on the purpose for which the map has been created. Thus a map for motorists needs to be at a scale where the limitations of printing size will allow sufficient area to be shown without being unmanageable, and the content will include significant features for navigation and a selection of the road network. If this is not sufficiently detailed a larger scale map has to be used but the penalty of less coverage and hence more map sheets has to be accepted. At the other end of the scale range are maps used for cadastral and planning purposes where scales sufficiently large to show street furniture such as lamp posts and manhole covers in their true position are used.

A map then is a representation of the real world where some selection of the content has taken place to service the needs of particular users which results in a specification which is a compromise between scale, content, accuracy, sheet size and finally the way in which the map is drawn and symbolised.

In order to use a map to unlock the information contained within it some skill in map reading is needed but once acquired it is a

relatively simple process for questions such as

- how far?
- where is?
- what is the distance between?
- how high is the ground at?

to be answered, while questions like

- can A be seen from B?
- what is the slope?
- which direction is the stream flowing?

can also be answered with more practice and some additional knowledge about maps. What cannot be answered without access to additional information are questions about the features in the map or related to them such as

- who lives at?
- how high is the bridge?
- what is the speed limit?

which are all simple examples of the kind of information contained in a Geographic Information System (GIS).

Thematic Maps

Between the topographic map and the GIS is a whole range of purpose built thematic maps which have been designed to portray information related to geographic positions and sometimes printed with the topographic map as a background. Examples of these are geological and soil maps. Demographic maps are often designed with symbols representing the quantitative information related to a geographic position, such as population to urban centres. This may be done using increasing symbol sizes. However there is a drawback to this display as any breakdown of the information requires yet another map, so that for information about the distribution of ethnic groups in the urban centres or the relative numbers by age or sex this becomes a cumbersome procedure. It is for this purpose that the GIS is so effective.

Digital Mapping

Before looking at GIS it is necessary to consider how a computer differs from a person when considering a map. People have a perception of maps which is affected by their knowledge of the real world, their experience and their intuition which interacts with the information within the map giving its relationship to the real world such as scale, orientation, symbolisation, projection and degree of generalisation. The two latter items affect the perception by introducing degrees of distortion and displacement which complicate

the way in which the map is interpreted. Finally people have to contend with their preconceived ideas and even prejudices which distort the perception. Nonetheless the human brain is extremely efficient at extracting information from the huge amount of detail available in a topographic map.

Questions about relative position, slope, size, distance, and connectivity are rapidly answered whereas a computer would need to be given details which a person can rapidly infer, such as that there is no logical connection between a stream and a road even at a ford or that a motorway only connects to other roads at specific junctions.

However a computer programmed correctly and given the correct data can rapidly overcome differences which arise from projections and to some extent generalisation, which many people fail to understand.

In order to do this the data must include information which the computer program uses to distinguish the various parts of the map.

- geometry
- reference systems
- feature codes
- attributes
- topology.

Before looking at the way in which these are used it is worth considering the way digital mapping at the Ordnance Survey (OS), the national mapping agency of Great Britain, developed.

In the late 1960s it was thought that if digital processes could be effectively introduced to produce maps automatically from stored data it would be possible not only to emulate the existing map specifications but also through software to produce generalised maps at a variety of scales from the same data. During these early investigations there were few demands for map data beyond the map making processes so development concentrated almost entirely on using the data for map production.

Although some work was done on small scales, investigations concentrated on the production of digital data for the large scale urban mapping and the associated generalisation problems.

By the early 1980s a demand for digital map data was emerging for use as a background reference map for the display of information predominantly from the digitised records of cables or pipe lines of the public utilities. Data for this purpose did not require all the various coding which had been introduced for cartography and as a result, some reduction in content was introduced in order to make the data more acceptable. From about 1988 a demand for more sophisticated data has emerged partly to improve cartographic processes and more specifically to service GIS. However the predominant use of digital data in Great Britain remains at large scale (1:1250) for the recording of utility distribution networks, and at local government level where there is an increasing number of municipal authorities developing GIS/LIS for urban land management and physical planning. Although, investigations into the wide range

of possible applications in GIS are beginning to create demands for data at other scales.

Geometry

At the lowest level a digital map is composed of the coordinates which define positions on the earth's surface for all the features included in the data set. In its simplest form the coordinates which represent these features are collected in any order and the resulting strings of coordinates provide the information which the computer needs to reproduce a map. At this level there is no intelligence in the data, thus one coordinate string cannot be identified from another nor are the points where strings or lines cross specifically defined, unless the crossing point has been coordinated as a deliberate act.

Reference Systems

In order to introduce a relationship between coordinated points on the earth's surface and their representation as a map, computers rely on various reference systems though which scale and projection are related to the real world in exactly the same way that a conventional map establishes these relationships. The difference is that the conventional map series has the scale and projection determined as part of the specification whereas computers are capable of varying projection and scale rapidly and accurately. In practice a coordinate reference system is selected for a particular country and application which here in Great Britain is the National Grid but a system based on latitude and longitude or Universal Transverse Mercator could be used with equal effect. Provided there is a relationship which can be programmed into the computer system transformation of coordinates between reference systems can be carried out. For a computer the concept of scale is not significant since scale is dependent purely on the relationship between the screen display and the real world. What is of much greater importance is the resolution of the coordinates which have been captured since coordinates captured to the nearest 5 metres may be quite adequate for a scale of 1:50 000 whereas at 1:1000 they do not have sufficient accuracy for that resolution.

In addition to the coordinate reference system there are other ways of selecting locations in the digital data such as addresses and postcodes but these are dependent on being included in the data set with suitable pointers to the coordinate system so that they can be recognised by the computer program.

Feature Codes

To unlock the relationship between a line in the data and a feature in the terrain the computer needs to be told what the coordinate strings represent and this is the basis through which the digital data takes on a more coherent form. Each line in the data is assigned a feature code which identifies what it represents on the ground. Thus a building outline can be separated from the fences which bound the land parcel and the edges of a road can be identified as being made up of a series of lines, coded building, fence, ditch etc through linking them to the centre line which acts as a pointer to the edges. In a similar way point objects can be

coded so that the correct identification can be assigned and the correct symbol displayed.

Attributes

Having located the lines through coordinates and identified what they represent, additional information can be assigned through seed points in the data. In a cartographic context these attributes would be the line styles such as pecked lines for road curbs or line weights depending on the specification and would include road names and house numbers. Attributes can arise from a number of sources and, in a GIS, seed points in the map data are linked to non-spatial data in associated databases to give the geographic relationship to that data.

Topology

In order to perform properly, within a sophisticated information system the data needs to be structured in such a way that the computer can readily determine the logic in the data, while still relying on the geometry and the feature codes to define the features. In topologically structured data the component parts of the data are identified so that significant junctions are made into unique points called nodes while the lines between the nodes regardless of whether sinuous or straight are termed links. Only where two links cross which have a significant connection in the real world are the links broken and a node created. Thus where a power line crosses a fence the two links would cross without a node at the crossing point. In topology the data is formed into polygons and seed points are created so that attributes can be related to the objects formed by the polygons. This concept allows the inside and outside of a polygon to be separately identified and linked to separate attributes. It is now possible to identify objects in the data so that a collection of building polygons with a perimeter and possibly separate but associated polygons, can be identified as a school. It is a short step from here to catchment analysis given the school pattern and the location of the homes of school age children or even the planning of school bus routes to transport the children to school.

In addition to the polygons formed from the links, topology makes possible the identification of networks so that either river or road networks can be formed for analysis in relation to the attributes which can be attached to the links.

Finally there are relationships which identify the connectivity so that the link which passes under can be identified in its spatial position relative to the link passing over.

A prime example of a topological map is probably familiar to most people who visit London, without realising the significance of the diagram. The London Underground map has no geometric framework, it has variable scale and the positions of the stations only very approximately give their relationship to other stations particularly those on another line. However what is shown is the network and the connectivity which allows a route to be planned but which, without some knowledge of the true shape of the layout in relation to the city streets, may not always result in the quickest journey. A GIS

application could very simply be designed to produce such a result if journey times were attached to each link and coordinates were assigned to the stations to relate them to a suitable topographic map.

Levels of use of digital data

There are three main levels of use for digital map data. In the early days of digital mapping data increased in complexity from level 1 to level 3, but recent improvements in map production can only be achieved with data which satisfies many of the requirements of level 3.

Level 1 - Data for the production of maps and plans.

The use of digital map data makes it possible to produce maps to a variety of scales and content. The simplest form of data which includes geometry and feature coding is capable of map production to a specification which does not include symbols or ornamentation. However fully automated production can be achieved through the improvement of the data by using polygons which contain seed points to indicate where symbols and ornamentation are to be included. Thus woodland, slopes and building stipples can now be plotted in their correct style and position automatically. This more versatile data makes it possible to eliminate the constraints of sheet size, map layout and within limits, scale. It also allows the map design to be changed through alteration of the symbols and the addition of colour, and with special software can carry out a certain degree of generalisation automatically.

Level 2 - Background to user data.

Even using the simplest form of digital map data will allow information such as pipeline routes to be recorded against the digital map background. The result can be displayed on a screen or plotted as a composite document, but until additional intelligence is included in the map data it is only possible to analyse the associated user data to the level of intelligence in that data. Thus it would be possible to obtain information about the pipeline network such as pipe sizes, material flow, etc, but any underlying information relating to the customers being supplied could not be accessed through the map data without a more sophisticated map dataset with associated attributes which would be essential for GIS applications.

Level 3 - Component of a GIS/LIS.

Although level 2 is a simple GIS, in order to be used as a component of a GIS/LIS the map data would need to include sufficient topology to make the attachment of both graphic and non-graphic attributes possible. In such an application it would be possible to relate the digital map data to associated databases which would allow various separate sources of information to be related through the spatial reference system of the map data. In the case of utility records it would be possible to identify the house number or name, the occupier, consumption, billing details, etc.

Geographic Information Systems (GIS)

There are numerous definitions of GIS but all err on the side of brevity leaving out as a result many of the functions of GIS by not specifying exactly what it includes.

The essential nature of a GIS is that it should be capable of linking a variety of data through a common spatial reference system. A GIS allows the collection, updating and display of a number of unconnected data sets bringing them into a common reference system for spatial analysis from which relationships can be identified and decisions made. Through the structure in the data it is possible to link non-spatial data to the polygon seeds and to individual links in the map data and to manipulate the various data sets as one data set.

A GIS is not concerned primarily with maps. While a map may be a way in which to access the data and simplify storage it is the spatial reference system which allows the analysis and integration of datasets to happen effectively. However when it comes to the display of results there is no better way in which to show location and relationship between sites or events than the digital map. When this is done it is important to produce a clear and concise map to a high quality which in turn adds credibility to the results. The structure and feature coding in the map data allow the data to be manipulated to produce maps which are suitable for display.

Finally the map has various components which when attributes have been attached, can be used to provide analyses of polygons or networks. Special subsets of the map data can be used to create specialised data products to support specific GIS applications. When used in these ways the map data takes on a high level of importance as a GIS component.

Land Information Systems (LIS)

For the purpose of this paper an LIS is defined as a subset of GIS attributes. The principal difference being that an LIS uses large scale digital map data as a base on which to overlay land related digital information in a computer system for the specific purpose of managing land related activities. This usually requires digital map data captured at large scales (1:1000 - 1:10 000) in order to provide a topological base to show the relative position and relationship of buildings/land plots. The definitions of the previous paragraph in bold type apply also to LIS.

OS Achievements with Digital Map Data

By 31 March 1991, the OS will have completed the digitising of all published national plans at 1:1250 scale, (this scale of mapping covers urban centres with a population of more than 20,000). The digitising of 1:2500 scale mapping covering the smaller towns and populated rural areas is also proceeding rapidly, and is 20% complete.

In order to make this structured digital data available to all potential users for their GIS/LIS use, the OS has developed the National Transfer Format (NTF) which is capable of transferring data

As an example of GIS in a planning role the digital map of an area shows the field boundaries, road layout, buildings and some information about the land use such as woodland, orchards, marsh etc. If the pattern of land ownership is added, together with information about the existence or otherwise of planning permission it is possible to determine the development potential and suitability of various sites on offer. The map background makes it possible to display the various analyses and also can provide details about access and parcel areas which together with land values would provide a good basis for making a decision about a development proposal. However simple it may appear the components of a GIS have to be collected and integrated into the GIS, thus in this example unless the ownership of the land can be established and which parcels already have planning permission the initial stage in the process must be data collection and this should not be underestimated in either time required or cost to do it.

The previous example has illustrated large scale map data applications which show an overlap of GIS and LIS, but a GIS is equally suited to the consideration of problems over wider areas where factors affecting the environment can be studied in relation to their effect on the population. One such study by a Regional Research Laboratory is concerned with the investigation of the reasons why clusters of cases of childhood leukemia occur. For this study the map base needs to be of sufficient resolution to show the location of population centres significant to the study over the whole area and yet be suitable for display of smaller areas at larger scale.

The population census data being collected in 1991 for the UK will create the requirement for map displays based on the small scale maps of the country combined with the ability to display data related to local government wards, census enumeration districts and possibly unit post codes in the urban areas. Thus the generalisation inherent in the maps will have to be introduced into the non-graphic data to allow macro spatial analysis to be carried out from the detailed data which the census will provide.

In a similar way data for in-car navigation is a combination of the macro route network and the very detailed road systems in the urban areas. Attributes relating to the road network which include direction restrictions, speed limits, bridge heights, width restrictions etc which are of a permanent nature or change infrequently, and those of an ephemeral nature such as lane restrictions, road works, accidents etc are linked to relevant points in the map data to create a complete database of the road network which can be used for a variety of applications ranging from in-car navigation to route-planning. Clearly a database of this sort combined with traffic patterns and volumes would be able to answer questions such as - what happens if main interchanges on national highways are closed on national holidays?

LIS Applications in the UK

At the municipal level, Milton Keynes Development Corporation has created a corporate land information system which is used to keep all the land transactions and associated records of occupancy, ownership, leasehold etc.

With reference to Land Title Registration, both HM Land Registry in England and Wales and the Registers of Scotland now have active programmes to transfer title records from the existing OS cadastral plans onto OS digital map data.

In Great Britain, because the national digital map data is both topographic (geographic) and cadastral (land) there is a tendency for GIS and LIS to overlap.

Conclusion

The foregoing has given a very brief description of some of the considerations concerning digital mapping, its relationship to GIS/LIS and developments and applications in the UK. There are many other factors for which there is insufficient space and time to give a mention. It must be remembered that for a GIS/LIS to be effective it needs sufficient data for the investigation in hand and where data is not available its collection is a major consideration.

Not only is data a major resource but its management and maintenance are of prime importance. Out of date information will give flawed results but an out of date background map is of equal concern. Revision of the map base affects the whole GIS/LIS and it is absolutely vital that the way in which this is carried out is carefully considered as part of the GIS/LIS design.

Selected Bibliography

Principles of Geographic Information Systems for Land Resources Assessment, Professor P A Burroughs, Oxford University Press 1986.

Geographic Information Systems: Overview, Principles and Applications edited by Maguire, Goodchild and Rhind, shortly to be published by Longman Scientific and Technical UK.

Cartographic Design and Production 2nd Edition, John S Keates, Longman Scientific and Technical UK 1989.

Land Information Management, P F Dale and J D McLaughlin, Clarenden Press, Oxford 1988.